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Evaluation of the production of biogas from the codigestion of jatropha press cake and chicken manure

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ABSTRACT

Anaerobic co-digestion of jatropha cake and chicken manure was investigated in a batch process. Experiments were designed with different mixing ratios and different parameters that affect biogas production were investigated. Five lab scale digesters A, B, C, D and E were prepared to digest the solid substrates. Sun dried CM was used during the codigestion process and the process was carried out at room temperature and pressure. The water displacement technique was utilised to examine the capacity of the produced gas. It was found that the production rate of biogas increased with an increase in temperature and pH, thus biogas production is temperature and pH dependent. A maximum biogas yield of 210 ml was recorded and its mixture ratio of 75%JC: 25%CM was chosen as the optimum mixing ratio.

Keywords: Jatropha press cake; Chicken manure; Anaerobic co-digestion; Fermentation; Sustainable energy; Fossil fuels; Biogas production.

1. Introduction

Biogas production has attracted attention in the energy sector as a renewable energy source that is sustainable and economic in nature. The purpose of this paper is to assess the feasibility of the anaerobic codigestion of jatropha press cake and chicken manure. For the past decades, globally nations have entirely depended on fossil fuels and this has led to an increased carbon footprint within the atmosphere. The overreliance on fossil fuels has resulted in increased greenhouse gases thus depletion of the ozone layer and the depletion of those fossil fuels (Esterhuizen, 2011). Researchers are currently looking into alternative sources that are renewable and sustainable in nature to replace the fossil fuels. Biogas is one of the energy sources that can be adopted to solve the problematic behaviour associated with fossil fuels (Muzezewa & Eng C, 2017). Presently a research has been carried out on the production of biodiesel from jatropha curcas seeds. A positive result has been achieved in terms of biodiesel production. However, during the biodiesel production by oil press screw machines, a residue cake is produced known as jatropha press cake (JC). There has been a rising concern in terms of its disposal. JC is a hazardous cake which contains toxins such as cursin which make it unsuitable for animal feeding. In addition to that when it decomposes it produces an odour and pathogen thus affecting the overall pH of soils, ultimately affecting the nutrient content of the soil. Basically, there is need to improve the disposal of jatropha press cake and thus its use in biogas production is a positive step in solving the problem. Biogas has been produced from jatropha press cake however it has been reported that codigestion will improve the biogas production capacity of the JC (A.H & Razaq, 2016). Since JC contains relatively high solids and volatile solids it can be mixed with chicken manure to produce more gas at a relatively smaller retention time. Chicken manure (CM) produces relatively small amounts of biogas mainly because of its high ammonia inhibition. The substrate has high nitrogen content and thus codigestion with a substrate with high organic load will result in increased gas production due to their synergistic effects.

Codigestion of different substrates has been carried out and positive results have been reported. According to (Jupta & Dhanya, 2009) co digestion resurfaces as the easiest and somehow achievable way to increase biogas yields. Animal manure and crop residues have been used for quite some time as substrates for anaerobic co digestion to produce biogas. From their results (Jupta & Dhanya, 2009), the co-digestion of Jatropha fruit coat and cattle dung in the ratio 1:2 reported high biogas yield as compared to the sole substrates, cattle dung and Jatropha fruit coat alone. At a total solid's concentration of 15%, the biogas yield from a ratio of 2:1 cow dung as to Jatropha fruit coat was 403.84 L/kg dry matter and the high biogas yield can be related to the interactive action of the microorganisms from the co digestion process. Chicken manure was co digested with kitchen wastes (Kukkonen, 2014), cow dung, pig manure (Nnabuchi M.N, 2012), sewage sludge and corn stalks (Xiaojiao Wang, 2012) and in all cases increases in biogas produced was noticed. From all these reports the sole anaerobic digestion of chicken manure produces less biogas as compared to the codigestion mixture. This low biogas generation is attributed to the high organic nitrogen content of the chicken manure. Generally, the codigestion of chicken manure with jatropha press cake can serve as an easy means to reduce environmental pollution through the waste management technology of anaerobic codigestion. To add on to that, a renewable energy source biogas and a residual fertilizer will be produced. In short, anaerobic codigestion of jatropha press cake and chicken manure is an economic way of managing the two waste products into a more valuable energy source.

1.1. Jatropha plant in Zimbabwe

Jatropha curcas plant is a shrub which grows to about 3-5metres in tropical and subtropical regions. It has a seed-bearing capacity of about 50 years, and it can be propagated from cuttings or seeds. Due to the rapid fuel shortages in Zimbabwe, jatropha seed was exploited as a fuel source. Jatropha curcas seed produce biodiesel through a process known as transesterification. The oil is expelled from the seed through oil press expellers. When 100kg Jatropha carcass seeds are oil pressed, about 30% is extracted as oil and the 70% remain as Jatropha press cake. This press cake is a waste by product from the biodiesel production and is not suitable as animal feed because it contains toxins that are harmful to both human and animal life. The press cake is high in organic matter with about 94% total solids hence it is suitable for biogas production (Raphael M. Jingura, 2010). Finealt Engineering in Mtoko is currently producing biodiesel from the drought resistant shrub. Due to the lack of a proper disposal method, the JC is dumped on ground surface and this causes an environmental problem. When JC decomposes it releases toxins that seep into the ground and results in changes in soil pH and ground water mineral content. Pathogens and insects also result from this type of disposal. However, due to its high volatile solids content, JC can be utilised in biogas production.

1.2. Chicken industry in Zimbabwe

Poultry farming has gained a portion in the farming sector for some decades now. The poultry industry is growing daily both in the rural and urban setup. According to (Nyoni, 2019), Zimbabwe's poultry industry has logged a 32% rise producing about 90.8 million-day-old chicks in 2018. Many farmers have always used chicken manure as an organic fertilizer globally. However, some of the chicken manure is being dumped and thus posing as a threat to the environment. Chicken manure produces a bad odor that results in air pollution. In addition to that animal manure

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without proper management also attract insects, rodents and the release of animal pathogens and surface to ground water contamination (Tamas Bojti, 2017). Chicken manure is known for its high nitrogen content and thus its utilization in biogas generation is possible as it provides the protein structure required by the microorganisms for building their cell structure. The residual after digestion can be used as a fertilizer.

2. Materials and Methods

2.1. Substrate, inoculum collection and preparation

The JC used for the experimental procedure was collected from Finealt engineering in Mtoko. Chicken manure and the rumen fluid used as inoculum were collected locally in Chinhoyi. The chicken manure samples were collected from CUT farm and the rumen fluid was collected from KOALA abattoir Chinhoyi. Chicken manure was sundried for 2 hours and then both substrates were ground to powder form using a mortar and pestle as shown in Figure 1. A 2 mm together with a 710 micrometer sieve were used to recover the fine particles. Rumen fluid was mixed with water in the ratio of 1:1 and the solid particle was separated by using a 2 mm sieve.

All the glassware used in the experimental investigation was washed with soapy water and rinsed with distilled water. An oven was used to dry the glassware and they were cooled before use.

Figure 1. Substrate preparation

2.2. Substrate characterisation

All the substrates were characterised according to the APHA standards. The volatile solids, total solids, water content and ash content were performed according to the standard methods outlined in section 2540. Temperature and pH of the substrates was measured using the K-type thermocouple and the online pH-863. The K-type temperature sensor was used to measure the digestate temperature throughout the experiment. For pH measurement, an online pH controller pH-863 is used. Data loggers displayed and stored the measured values respectively.

2.3. Experimental design

The experiment was carried out at room temperature and pressure and it consisted of five 5 liter containers that were loaded as shown in Table 1. To avoid severe temperature fluctuations, the biodigesters were insulated with saw dust. Two sets of sensors were utilised for temperature and pH measurement. Water displacement was used for gas measurement. The gas measurement system consisted of a measuring cylinder inverted in a beaker with NaOH

solution to absorb the carbon dioxide and allow only methane to bubble through. The experimental setup is shown in Figure 2 and Figure 3 shows the actual setup.

Table 1. Mixing ratios for the experimental study

Digester name	Mixing ratios	Inoculum
A	100% Jatropha press cake	500 ml
B	75% jatropha press cake and 25% chicken manure	500 ml
C	50% jatropha press cake and 50% chicken manure	500 ml
D	25% jatropha press cake and 75% chicken manure	500 ml
E	100% chicken manure	500 ml

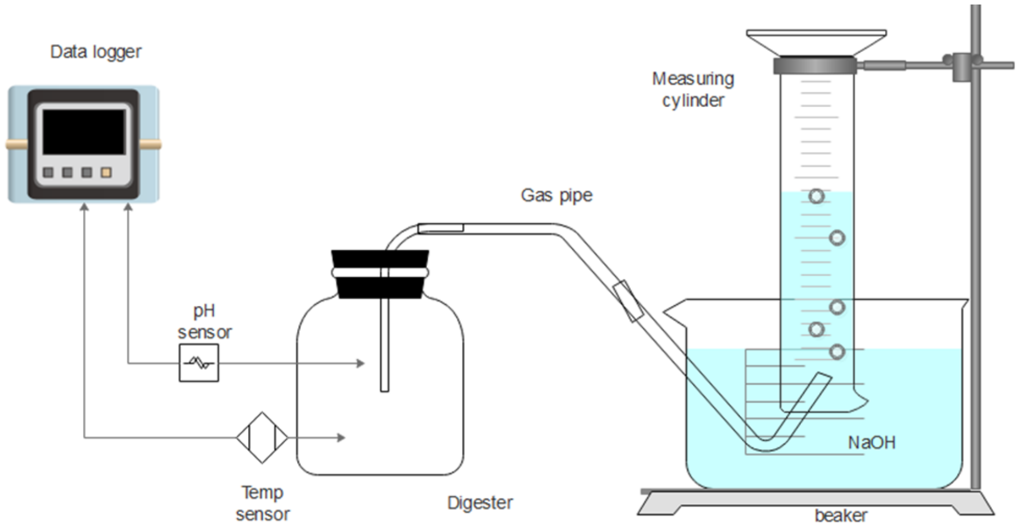

Figure 2. Experimental setup

Figure 3. Actual experimental setup

2.4. Results and discussion

2.4.1. Substrate characterisation

The substrates were characterised according to the APHA methods and the results are shown in Table 2. Proximate analysis was carried out according to the APHA standards and both substrates had VS contents of above 80%. The TS content was also greater than 83% and this clearly proved the suitability of the substrates for biogas generation.

Table 2. Substrate characterisation results

Parameter	Jatropha press cake	Chicken manure
Total solids %	94.10	83.31
Volatile solids %	80.75	87.85
Moisture content%	5.86	16.69

2.4.2. Biogas production

The biogas produced was measured by the NaOH displacement method and the cumulative gas produced was recorded.

2.4.3. Effect of mixing ratio on biogas production

JC and CM were mixed according to the mixing ratios shown in Table 1. Figure 4 shows the cumulative gas productions for each individual digester. An increase in biogas yield with increase in JC percentage was noticed. This can be attributed to the increase in organic matter content thus increased food for the microorganisms. The CM aided in providing the nitrogen for bacterial growth hence the high volumes of gas produced. CM is usually related to ammonia inhibition and that is the reason why digester D and E which contained higher amounts of CM recorded low gas volumes. Digester A contained 100% JC and thus it produced a gas volume of 85ml, and this is due to the high lignin content present in the cake that inhibits biogas production. These results correspond to those presented by (Sanjay L. Pal, 2015) from the codigestion of cow dung and JC. An increase in JC ratio resulted in increased biogas yield. An increase in JC results in increased nutrients for microorganisms to feed on and the presence of the cow dung increased the growth of microorganisms.

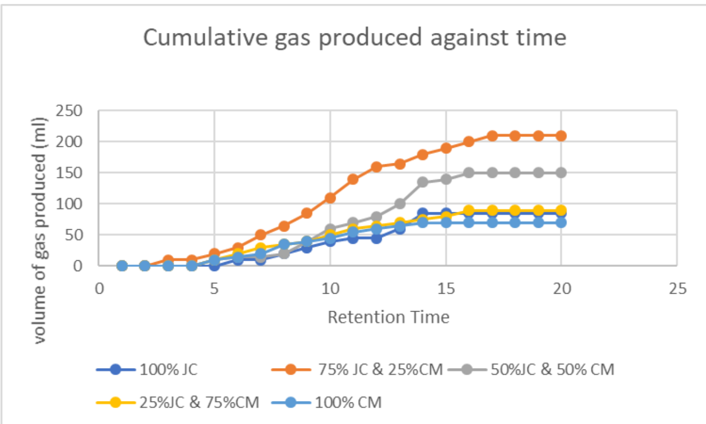

Figure 4. Cumulative biogas produced against retention time

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2.4.4. Effect of pH on biogas yield

pH variation was analysed for the digestion process. Figure 5 shows the pH variation against retention time. Initially on day 1, all digesters recorded pH below 7. This pH range was noticed to drop during first five days and pH values of around 5.4 were recorded. Low pH values destroy microorganisms thus the pH was corrected with a 1 molar $NaCO_3$ solution. The pH increased as shown in Figure 5. A pH range of around 6.2-7.5 is optimum for biogas production (Antony.P.Pallan, 2017) and all the digester recorded pH values within this range. Figure 6 also display that the biogas yield increased with an increase in pH thus the process is pH dependent. These results are similar to those presented by (Antony.P.Pallan, 2017) which showed that the anaerobic codigestion process is pH dependent. This is because of the presence of the methanogenic microorganisms that require neutral pH ranges for methane formation and also the fatty acids produced during the first and second stage of anaerobic digestion that lower the pH values and thus a drop in it causes less or inhibit biogas production.

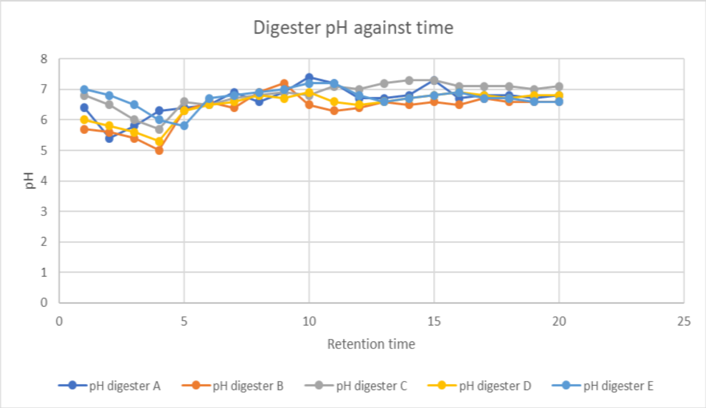

Figure 5. pH variation against retention time

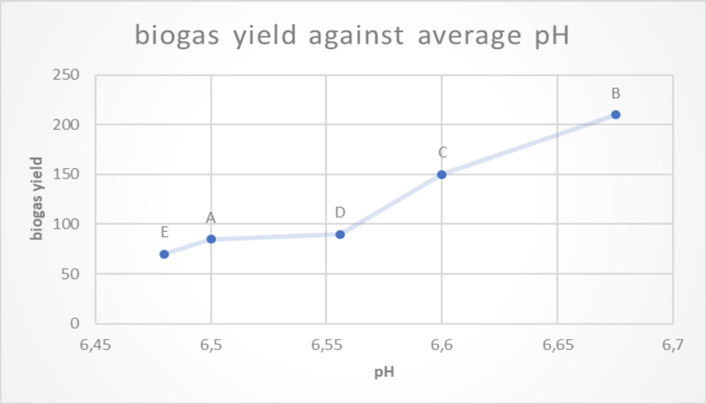

Figure 6. Biogas yield against average pH

2.4.5. Effect of temperature on biogas yield

Temperature is another essential factor that affect biogas yield (Joute Y., 2016). The experiments were carried out at atmospheric temperature and no mechanism of temperature control was employed. Figure 7 shows temperature variation in all the 5 digesters. The fluctuations are shown to be rapid. Figure 8 shows how biogas yield was influenced by temperature. As the temperature increased, the biogas yields also increased (Antony.P.Pallan, 2017). This clearly shows that biogas yield is temperature dependent.

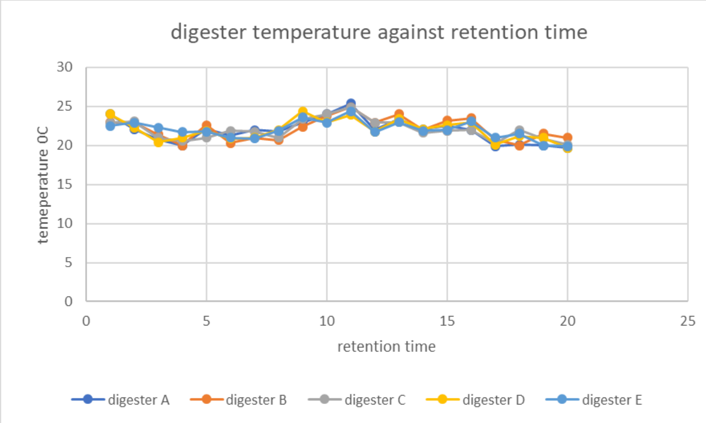

Figure 7. Temperature variation in digesters

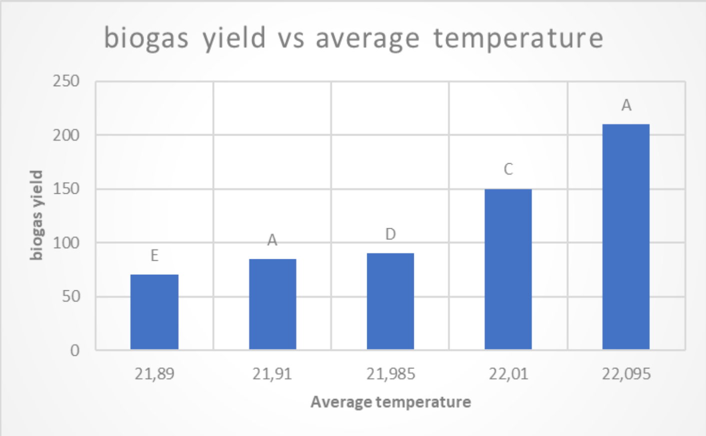

Figure 8. Biogas yield variations

3. Conclusion

The study clearly reviewed that chicken manure can be used to aid biogas production in JC. The utilization of these substrates for biogas production could eliminate their disposal problems and create another abundant source of sustainable energy. From the experimental results, an increase in biogas volume was recorded in the mixed samples. Substrate characterisation was performed in accordance with the APHA standards (Clesceri, 1999) and both substrates showed VS contents of greater than 80% showing a huge potential for biogas production. Different mixing ratios were prepared and the factors that affect biogas production were analysed. From the results, an increase in temperature and pH resulted in an increase in biogas yield, thus showing that biogas is temperature and pH dependent. An optimum mixing ratio for the two substrates was ascertained and it was found that 25%CM: 75%JC produced a maximum biogas yield within the optimum ranges of pH.

4. Recommendations

While research has explored the potential of co-digesting jatropha press cake and chicken manure for biogas production, further investigations are needed to optimize the process and ensure its sustainability. Some of the future recommendations for evaluation includes the optimization of mixing ratios and pretreatment methods by investigating the optimal mixing ratios of jatropha press cake and chicken manure for maximizing biogas yield while maintaining digester stability and exploring various pretreatment methods (physical, chemical, biological) to

enhance the biodegradability of both substrates, particularly jatropha press cake, which has a complex structure. Another recommendation is the long-term studies of process stability and sustainability of the co-digestion process, including monitoring digester performance, nutrient balances, and potential accumulation of inhibitory compounds and evaluating the impact of operational parameters (temperature, pH, organic loading rate) on digester stability and biogas production over extended periods. The third recommendation is the life cycle assessment and techno-economic feasibility based on conducting a comprehensive life cycle assessment (LCA) to evaluate the environmental impact of the co-digestion process, considering factors like resource use, greenhouse gas emissions, and potential environmental burdens and performing a techno-economic feasibility analysis to assess the economic viability of the process, including capital and operational costs, potential revenue streams from biogas and digestate, and economic sensitivity analysis. In addition, the integration with agricultural practices that is investigating the potential for utilizing the digestate (digested slurry) as a fertilizer in agricultural practices, evaluating its nutrient content, soil amendment properties, and potential agronomic benefits and developing strategies for integrating the co-digestion process within existing agricultural systems, considering waste management, nutrient recycling, and overall sustainability. In addition, the advanced process monitoring and control based on exploring the application of advanced monitoring and control systems to optimize digester operation, including online monitoring of key parameters (pH, temperature, biogas composition) and implementation of real-time control strategies and investigating the potential of using machine learning and data analytics to predict biogas yield, identify digester instability, and optimize process parameters for improved efficiency. Lastly, investigating the potential for scaling up the co-digestion process to pilot or commercial scales, considering technical and economic feasibility. By addressing these recommendations, researchers and practitioners can gain a deeper understanding of the co-digestion process, optimize its performance, and ensure its long-term sustainability and potential for contributing to renewable energy production and waste management solutions.

Declarations

Source of Funding

No funding source is reported for this study.

Competing Interests Statement

No conflict of interest is declared by the authors.

Consent for Publication

The authors declare that they consented to the publication of this study.

Ethical Approval

The authors stated that the study does not require ethics approval as it does not deal with humans or animals neither does it directly affect human social life.

Availability of data and materials

Data supporting the findings and conclusions are available upon request from corresponding author.

Authors' contributions

All co-authors have involved in all stages of this study while preparing the final version. They all agree with the results and conclusions.

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